METHOD AND APPARATUS FOR MONITORING CHANNEL FREQUENCY RESPONSE

Field of the Invention

The present invention relates to a method and apparatus for determining, storing and retrieving channel frequency characteristics for discrete multi-tone (DMT) and is particularly concerned with asymmetric digital subscriber lines (ADSL) and very high bit-rate digital subscriber lines (VDSL) using DMT modulation.

Background of the Invention

Digital Subscriber Line (DSL) is a well known access technology that uses existing 2-wire copper telephone wiring (also known as unshielded twisted pair UTP) to deliver high-speed data services to homes and businesses. DSL technology has become popular with both subscribers and Internet service providers because the service uses the customer's existing phone line and typically does not require an additional phone line. In addition, the signaling used by some DSL technology is above that used by plain old telephone service (POTS). Hence, this allows an "always-on" Internet access while still providing use of the phone line. Current ADSL technology offers users a choice of speeds up to about 8Mbps. This is much faster than a standard 56Kbps dial-up modem.

There are many types of DSL, generically these have come to be known by the designation xDSL. For any given line, for a particular type of xDSL, the maximum xDSL speed is limited by the frequency response of the channel which is a function of the distance between the subscriber and the central office (CO) and the filtering placed on the line, and by the noise conditions on the line which are primarily a function of crosstalk from other signals in the cable and ingress from AM radio

transmitters. On long loops speed frequency response and noise conditions of the channel bound the upper rate. On shorter loops the xDSL technology and its allocated bandwidth may be bit rate determining factor.

Asymmetric Digital Subscriber Line (ADSL) is one of the xDSL technologies that provide more bandwidth in one direction than the other, typically downstream from the central office to the subscriber. Very high bit-rate Digital Subscriber Line (VDSL) is a particular type DSL that may be configured as an asymmetric or a symmetric serive. It delivers from 13 to 52 megabits per second downstream bandwidth and 1.5 to 13 megabits per second upstream. VDSL may be implemented using single carrier or DMT based modulation. ADSL uses a form of modulation known as discrete multi-tone modulation (DMT). DMT is method of modulation that divides the available frequency range into sub-channels or tones, the number of sub-channels depends on the particular implementation.

ITU-T Recommendation G.992.1 also known as G.dmt, is a form of ADSL technology, using DMT modulation, that offers up to 8 MBPS downstream bandwidth, 1.544 MBPS upstream bandwidth. ITU-T Recommendation G.992.2 is also known as G.lite, is a form of ADSL technology, using DMT modulation, that offers up to 1.5 MBPS downstream bandwidth, 384 KBPS upstream. The rates mentioned above are not caps on the achievable data rate in these technologies but reflect rates discussed in the ITU standards documents.

The deployment of xDSL services in the copper loops helped service providers in providing new services and creating new revenues. However, the introduction of these services also created new challenges to the service providers in the maintenance and diagnostics area. Traditional methods of determining that a twisted pair is suitable for POTs service are not adequate for these higher frequency services. The rate determining factors of channel frequency response and noise can change over time, and require monitoring to ensure adequate service. These challenges include how to provide effective and low cost maintenance operation for the new services.

Summary of the Invention

An object of the present invention is to provide an improved method and apparatus for determining, storing and retrieving channel characteristics for discrete multi-tone.

Accordingly, the present invention provides method and apparatus for retrieving channel characteristics measured at a CO end of the channel by a CPE end of the channel. If the channel characteristics is determined at the CPE end and retrieved at the CO end, the first end of the channel means the CPE end and the second end of the channel means the CO end. However, if the channel characteristics is determined at the CO end and retrieved at the CPE end, the first end of the channel means the CO end and the second end of the channel means the CPE end.

To assist the ADSL service providers to meet the challenges discussed above, an embodiment of the present invention adds a physical layer protocol to retrieve the in-band downstream ADSL channel frequency response H(f), the noise N(f), measured at initialization and the signal to noise ratio SNR(f) measured at show time on a per bin basis.

An embodiment of the present invention also provides for retrieval of similar in-band information in the upstream direction.

Conveniently, an embodiment of the present invention adds the following parameters to G.992.1 bis and G.992.2 bis.

(a) The definition of the message protocol for retrieving during show time the following ATU-R information on a per bin basis:

i. In-band channel frequency response per bin $H_R(f)$ measured during the initialization referred back to the receiver tip and ring copper pair by the ARU-R.

ii. In-band noise estimation per bin $N_R(f)$ during the initialization referred back to the remote tip and ring copper pair by the ATU-R.

iii. The show time signal-to-noise ratio per bin $SNR_R(f)$. The values of $SNR_R(f)$ should be updated as they change.

(b) The addition of the programming interface in the ADSL ATU-C chipset level to make similar information available for the upstream direction, that is $N_c(f)$, $N_c(f)$ and $SNR_C(f)$. The conditions of them must be the same as the above.

(c) H(f), N(f) and SNR(f) are proposed as mandatory parameters.

The purposes of making the above information available are:

a) Initialization H(f) can be used for analyzing the physical copper loop condition between tip and ring.

b) Initialization N(f) can be used for analyzing the crosstalk.

c) Showtime SNR(f) can be used for analyzing time dependent changes in crosstalk levels and line attenuation (such as due to moisture).

d) The combination of H(f), N(f) and SNR(f) can be used for trouble shooting why the data rate cannot reach the maximum data rate of a given loop, scheduling maintenance and plant upgrade.

The invention is described mainly for ADSL. However, it may be similarly applicable to VDSL.

Brief Description of the Drawings

The present invention will be further understood from the following detailed description with reference to the figure in which:

Figure illustrates in a functional block diagram an asymmetrical digital subscriber line in accordance with an embodiment of the present invention.

Detailed Description of the Preferred Embodiment

Referring to the figure there is illustrated in a functional block diagram an asymmetrical digital subscriber line (ADSL) in accordance with an embodiment of the present invention. The ADSL 10 connects a customer premise equipment (CPE) 11 to a central office (CO) 12. The CPE 11 includes an ADSL modem 14 (ATU-R), POTS splitter 16, a computer 18 and a telephone 20. The CO 12 includes an ADSL modem 22 (ATU-C), a POTS splitter 24, and a telephone switch 26. The ADSL 10 effectively includes the ADSL modems 14 and 22 and the unshielded twisted pair (UTP) 28 there between. The ADSL arrangement of the figure is intended as merely representative and person skilled in the art of DSL would appreciate that POTS splitter 16 can be centralized as shown or distributed throughout the premise and attached to each telephoning device telephone, facsimile, or answering machine. Actual connections would depend on the version of ADSL used for example G-dmt or G-lite.

In operation, the customer connection via the ADSL 10 includes an initialization stage and a show time stage. The embodiments of the present invention enhance ADSL service maintenance and diagnostics by making diagnostic information available from both ends of the loop during active operation of the

service. The combination of complete information on the channel (H(f) and N(f)) during initialization plus show time SNR(f) is provided by the embodiment of the figure. This combination of data allows greater analysis of the line conditions than known methods and reduces interruptions of both the ADSL and POTS service that known methods require.

Embodiments of the present invention allow obtaining of useful information about the channel in which data is being transmitted.

An example of how the present invention could be implemented is now provided for the purposes of illustration. The embedded operations channel (EOC) defined in G.992.1 and G.922.2 are for communication between ATU-C and ATU-R. The EOC supports in-service and out-of-service maintenance and the retrieval of ATU-R status information and performance monitoring parameters (G.992.2, Section 8.1). As the proposed parameters are for maintenance diagnostics and performance monitoring, it is logical to add these parameters in the ATU-R data registers, so they can be retrieved through the EOC.

In G.992.1, registers 9_{16} and F_{16} are reserved for future use and in G.992.2, register A_{16} is currently being used. In order to apply the proposed registers to both G.992.1 and G.992.2 consistently, using register B_{16} and E_{16} is proposed.

Table9-3/G.992.1-ATU-R data registers

Reg. #	Use	Length	Description
0_{16}	Read(R)	8 bytes (see 9.3.3/G.994.1)	ATU-R vendor ID
1_{16}	R	Vendor discretionary	ATU-R version number minus one
2_{16}	R	32 bytes	ATU-R serial #
3_{16}	R	Vendor discretionary	Self test results
4_{16}	Read/Write (R/W)	Vendor discretionary	Vendor discretionary

5_{16}	R/W	Vendor discretionary	Vendor discretionary
6_{16}	R	1 byte	Line attenuation
7_{16}	R	1 byte	SNR margin
8_{16}	R	30 bytes	ATU-R Configuration (see 8.4 and Note 1)
9_{16}			Reserved (Note 2)
A_{16}			Being used in G.992.2
B_{16}	R	1024 bytes	The normalized channel frequency response $H_R(f)$ at ATU-R
C_{16}	R	2 bytes	The scale factor HS_R of $H_R(f)$
D_{16}	R	256 bytes	The noise $N_R(f)$ at ATU-R
E_{16}	R	256 bytes	$SNR_R(f)$ at ATU-R
F_{16}	Reserved	Reserved	See Note 2

NOTE 1—Registers shall be read most significant byte first.

NOTE 2 – Registers 9_{16} and F_{16} are reserved for future use; ATU-R shall respond UTC (unable to comply) if requested to read from or write to one of these registers.

The in-band frequency channel response, $H_R(f)$, is represented by a normalized complex number a(i) +jb(i) in the linear format, where I is the subcarrier index i=0,..., 255. Both a(i) and b(i) are coded as a two-byte 2's complement signed fixed point value respectively. The data format of a(i) and b(i) are the same. Bit 15 is a sign bit. The decimal point is on the right of bit 15. The accuracy is 1/32768. In the register, the msb is stored as the left byte and the Isb is stored as the right byte. The value of a(i)+jb(i) must be referred to tip and ring of the copper loop.

The first two bytes in $H_R(f)$ register store the real part (a) of a(*i*)+jb(*i*) for bin 0 and the second two bytes store the imaginary part (b) of a(*i*)+jb(*i*) for bin 0 and so on. The last four bytes stores the a(*i*)+jb(*i*) values for bin 255 for G.922.1 or bin 127 for G.922.2. A value of (-1-j) in a(*i*)+jb(*i*) is a special value. It indicates that this bin is

either out of the downstream PSD mask or this bin is not used for the data transmission (eg it may be because of the attenuation is too large, so that the SNR is too small or it is the DC subcarrier or the Nyquist subcarrier). The data range is between –32767/32767/32768 inclusive. The register reserves space for all 256 bins, as it is easy for application user to remember.

It is suggested that the reported channel frequency response values be partitioned between the scale factor and per carrier complex components such that max(|a(i)|, |b(i)|) over all i is equal to 32767/32768 in order to maximize precision.

The $H_R(f)$ register is only updated during the ADSL initialization stage. This information can be retrieved during show time, however, it may not be updated during show time.

The scale factor HS_R is coded as two bytes 2's complement unsigned fixed point value. The decimal point is on the right of bit 15. One bit is used for integer and 15 bits are used for the fraction. The accuracy is 1/32768. In the register, the msb is stored as the left byte and the 1sb is stored as the right byte. The data range is between 0 and +(1+32767/32768) inclusive. There is no special value for it.

This data range supports a dynamic range of approximately +6dB to –90dB. The portion of the scale factor range above zero is necessary to accommodate the possibility that on short loops, given manufacturing variations in signal path gains and filter responses, it is possible that the channel may appear to have gain rather than loss.

The HS_R scale factor register is only updated during the ADSL initialization stage. This information can be retrieved during show time, however, it may not be updated during show time.

The conversion of the normalized value of a or b to the absolute value can be obtained by multiplying a or b by HS_R.

The in-band noise, $N_R(f)$, is coded as a one-byte unsigned integer. The unit is in dBm/Hz. The accuracy is 1 dBm/Hz. Since the noise in dBm/Hz is a negative value, a value of 95 means-95dBm/Hz. The noise values must be referred to the tip-ring of the copper loop.

The first byte in $N_R(f)$ register stores the value for bin 0 and the second byte stores the value for bin 1 and so on. The last byte stores the value for bin 255 for G.922.1 or bin 127 for G.992.2. A value of 255 is a special value. It indicates that this bin is either out of the downstream PSD mask or this bin is not used for the data transmission (e.g.. It is the DC subcarrier or the Nyquist subcarrier). The data range is between 0 and 254 inclusive, where the highest value 255 is reserved as the special value.

The $N_R(f)$ register is only updated during the ADSL initialization stage. This information can be retrieved during show time, however, it may not be updated during show time.

The in band $SNR_R(f)$ is a one-byte unsigned integer. The unit is in dB. The accuracy is 0.5dB. For example, a value of 00000001 represents 0.5dB and a value of 01000001 is 64.5dB.

The first byte in the $SNR_R(f)$ register stores the SNR value for bin 0 and the second byte stores the $SNR_R(f)$ value for bin 1 and so on. The last byte stores the $SNR_R(f)$ value for bin 255 for G.922.1 or bin 127 for G.922.2. A value of 127.5 is a special value. It indicates that this bin is either out of the downstream PSD mask or it is not used for the data transmission (e.g. it is the DC subcarrier or the Nyquist subcarrier). The data range is from 0 to 127 dB inclusive, where the highest value 127.5 is reserved as the special value.

The $SNR_R(f)$ register is updated during the ADSL show time. It is updated as changes occur.

The upstream channel frequency response $H_C(f)$, the scale factor HS_C, the noise $N_C(f)$ and the signal to noise ratio $SNR_C(f)$ are available in the ARU-C. Currently, no programming interface is available at the chipset level to allow for diagnostics purposes of the ADSL service. The data definitions and their formats should be the same as the ones proposed for the downstream direction in this contribution.

With the existing information available from ITU G.992.1 and G.992.2 as well as from embodiments of the present invention, the ADSL maintenance and diagnostic capabilities can be enhanced.

The retrieved information, in at least one embodiment, can be used for remotely analyzing the physical copper loop condition between tip and ring. That is for:

- analyzing the crosstalk at both ATU-C and ATU-R, i.e. analyzing time dependent changes in crosstalk levels and line attenuation (such as due to moisture);

- trouble shooting why the data rate cannot reach the maximum data rate of a given loop.

The above capabilities would otherwise require a truck roll plus the use external test equipment.

The disclosed embodiments propose a new way to collect information available in the ADSL modems, such that this information can be used for enhancing the ADSL services maintenance and diagnostics. For the information required from ATU-R, the embodiments of the present invention save the information (per bin frequency channel response, per bin signal to noise ratio and per bin noise) in the ATU-R register. The information saved in the register is the frequency channel

response and noise information as measured during the modem initialization. This information is reflected back to the tip and ring of the copper pair. The signal to noise ratio information is the show time information. A further embodiment also provides the provision of the programming interface to allow for retrieval of the same information on the ATU-C side.